CUSTOMER NO. 30430

PATENT APPLICATION
Docket No. 01-OT-080

O I P E
SEP 2 1 2005
PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re patent application of:
Wang

Serial No.: 10/028,805 | Group No.: 2665

Filed: December 19, 2001 | Examiner: L. Yang

For: Method and Apparatus for Application Driven Adaptive Duplexing of Digital Subscriber Loops

MAIL STOP AMENDMENT
Commissioner for Patents
P. O. Box 1450
Alexandria, VA 22313-1450

CERTIFICATE OF MAILING
I hereby certify that this correspondence is being sent by first class mail in an envelope addressed to: Mail Stop Amendment, Commissioner for Patents, P. O. Box 1450, Alexandria, VA 22313-1450
on: 09-19-05

Signature Margo Barbarash

Dear Sir:

DECLARATION OF XIANBIN WANG
PURSUANT TO 37 C.F.R. § 1.131

I, Xianbin Wang, state that I am the applicant in the above-captioned application and the inventor of the subject matter claimed therein. Prior to May 22, 2001, I had completed in Canada my invention as described and claimed in the above-identified application as evidenced by the following:

1. Prior to May 22, 2001, I conceived of the invention. A date redacted, but nonetheless dated prior to May 22, 2001, copy of my invention disclosure is attached hereto as Exhibit A. At the time of the invention, I owed a duty of assignment of the invention to STMicroelectronics, Inc.

DALLAS2 1127403v1 28940-00116

2. After I conceived of the invention, I submitted a description of the invention to the appropriate STMicroelectronics patent review office for purposes of obtaining approval to file a patent application for the invention.

3. To the best of my knowledge, the STMicroelectronics patent review office followed its standard procedures in reviewing and subsequently approving of the filing of a patent application.

4. On information and belief, on or about September 24, 2001, a description of the invention was forwarded to one of STMicroelectronics' patent attorneys for preparation of a patent application.

5. On November 20, 2001, I was forwarded a first draft of a patent application prepared by the outside patent attorney. A copy of the transmittal letter sending the draft to me for review is attached hereto as Exhibit B.

6. On December 5, 2001, I was forwarded a final draft of the patent application, which had been revised in accordance with my comments. A copy of the transmittal letter sending the draft is attached hereto as Exhibit C.

8. I executed the above-captioned patent application on December 16, 2001 (see, my signed declaration filed with the application), and the application was filed on December 19, 2001.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States

Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Respectfully submitted,

By: Xianbin Wang

Xianbin Wang
68 Nortoba Cres., Kanata
Ontario K2T 1K6
Canada
Tel: 1-613-599 3060

01-OT-080

METHOD, SYSTEM AND OPERATION FOR ADAPTIVELY DUPLEXED DIGITAL SUBSCRIBER LOOPS

Xianbin Wang, STMicroelectronics

[redacted]

Field of the Invention

The present invention relates to digital subscriber loop (DSL) system and more particularly to optimal duplexing of the physical links of the DSL systems in the same cable bundle.

Background of the Invention

With the advent of inexpensive computers, the demand for residential broadband services has been increasing due to the widespread use of computers and the rapid development of computer networks. As a result, various Digital Subscriber Line (DSL) services have been proposed to make full deployment of the existing copper loop plant for the global information highway. DSL includes a large family, such as asymmetrical DSL (ADSL), high data rate DSL (HDSL), very high data rate DSL (VDSL) and so on, which forms a family loosely called *x-type digital subscriber line* (xDSL) technologies, where *x* stands for one of several letters of the alphabet.

Exhibit A

Current duplexing technique in DSL is fixed for certain DSL modems. The duplexing method determines how the overall bandwidth of a physical link is shared between the upstream and downstream transmission directions. For example, HDSL is symmetrically duplexed, i.e., the bandwidth for upstream and downstream are the same. And the bandwidth of ADSL link is asymmetrically duplexed, with more bandwidth is allocated to downstream. The basic assumption behind previous ADSL is that ADSL user is mainly receiving data from Central Office (CO) all the time.

While asymmetrical DSL is likely to be the most attractive option for casual Internet users, Symmetrical DSL (SDSL) is the most popular with businesses and teleworkers. SDSL meets the requirements of these segments, because this enables workers to send and receive large files from corporate servers with high speed in both directions. As the business and teleworker segments are predicted to be early adopters of DSL services, SDSL is an important offering.

Another important fact is that different DSL duplexing techniques may be desired by the same user for different DSL applications. For example, when the video conference application is activated through DSL link, symmetrical link is optimal. However, asymmetrical link is desired when an upload application is launched at a later time. It is to be noted here that the high data rate direction is not necessarily the

downstream direction. And the duplexing ratio between upstream and downstream bandwidth can be varied on an application basis.

Obviously, with current fixed duplexing technique, certain user main use one application for most of the time with an infavorite duplexing technique for him. It would be significant if the DSL duplexing can be adapted for different applications. Unfortunately, all the DSL systems available today cannot provide such kind of service in spite of the need to optimize the duplexing of the DSL link.

To implement the DSL modems which can provide adaptively duplexed link and operate such DSL systems cost effectively, the following factors have to be took in account during the system design process:

- The design of digital signal processing (DSP) blocks in the DSL modems to meet the requirement of different bit rate for downstream and upstream due to the changes of duplexing. The differences between these two data stream can be substantially large. And the bit rate of the upstream can be much higher than downstream to meet some uploading applications.

- The digital front end (DFE) and analogue front end (AFE) of the modems has to be changed correspondingly with the bandwidth changes of the downstream and uptream.

- The spectrally compatible operation of adaptively duplexed DSL systems in the same cable bundle. As the bandwidth of the upstream and downstream can be substantially different with previous ADSL, near-end crosstalk may be generated to some existing DSL modem in the same cable when the duplexing is to be adapted for a certain DSL user. Therefore, the transmission power and bandwidth changes resulted from the adaptation may have to be refrained. Certain management rule at Central office side has to be established such that different DSL application can be accommodated in the same cable sheath. This will be discussed in details in the following sections.

Application Area

With the adaptively duplexed DSL, the upstream and downstream data rates are substantially different for different applications. The duplexing techniques can be set according to DSL users when different application is launched or adapted on-line by some system management rule. Some application examples are:

- Internet and remote LAN access,
- Home office applications,
- File transfer (Upload and Download),

- Video on demand,
- Video Conferencing,
- Interactive games,
- Home shopping.

Modem Architecture

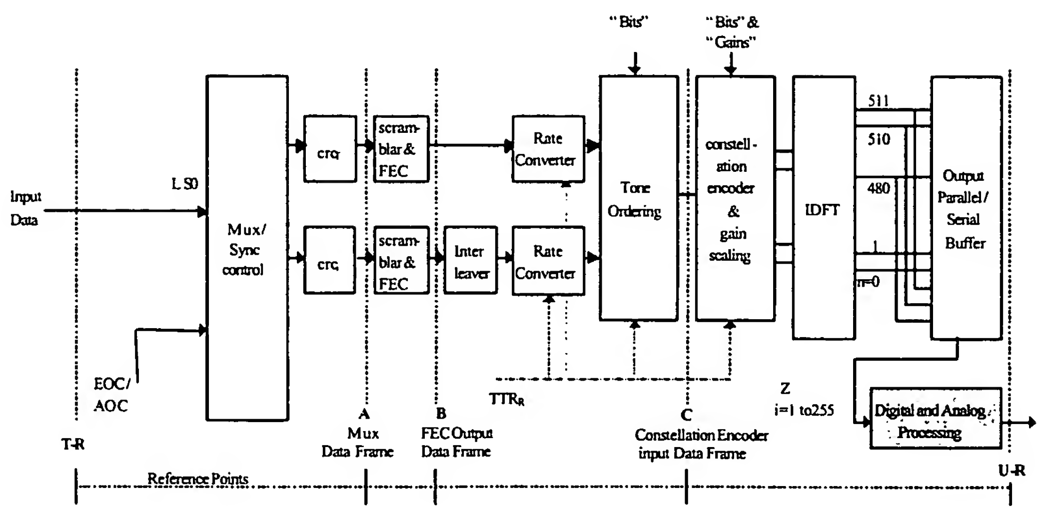

FIGURE.1 ATU-C (ATU-R) TRANSMITTER MODEL

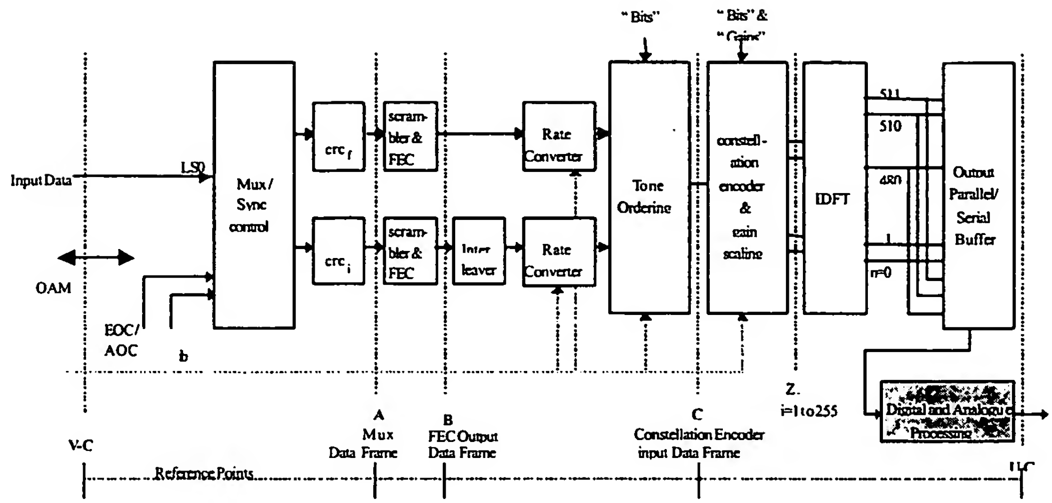

FIGURE 2 ATU-C TRANSMITTER MODEL

Figure 1 shows the functional blocks and interfaces of the ATU-R and ATU-C receivers for the adaptively duplexed DSL modems. The block diagram for ATU-C transmitter is plotted in Figure 2. The ATU-R transmitter is similar to ATU-C receiver but without the OAM path. We can see an important characteristic of this system is that the architecture of the receiver is symmetrical with the transmitter in the sense that a 512-point IFFT is employed. The difference between the transmitter and receiver is in the digital and analogue processing blocks, which is highlighted in the shaded region in Figure 1 and 2.

Basically, DMT signals and voice signals are combined at the customer premises end, and transmitted to the central telephone office. Then the voice signals are filtered and connected to the PSTN switch, while the data signals from many subscribers are fed into the access

multiplexer, which is connected to the network. And vice versa for the other transmission direction.

With the modems depicted in Figure 1 and 2, different duplexing method can be implemented on the same DSL link. Theoretically, duplexing ratio between the upstream and downstream bandwidth can be set arbitrarily. However, only a limited number of options can be implemented due to the cost and complexity of modems. A sample of the duplexing options is listed in Table 1.

Upstream (Subcarriers)	8	32	64	96	128	160	192	224	248
Downstream (Subcarriers)	248	224	192	160	128	96	64	32	8

Table 1. A sample duplexing options for DSL upstream and downstream.

- Modulation by the inverse Fourier Transformation.

The modulating transformation defines the relationship between the real time domain samples x_n and the IDFT input Z_i is

$$x_n = \sum_{i=0}^{511} \exp\left(\frac{j\pi ni}{256}\right) Z_i$$

n=0, ..., 512.

The constellation encoder and gain scaling generate only M complex values of Z_i, where M is the number of the subcarriers for the

transmitter and less than 256. In order to generate real output x_n from IDFT, Z_i is first mapped to Z_i' with

$$Z_i' = \begin{cases} 0 & i = 0 \\ Z_i & 1 \le i \le M \\ 0 & M < i \le 256 \end{cases}$$

The vector Z_i' shall be augmented such that the Z_i' has Hermitian symmetry. That is

$$Z_i' = conj(Z'_{(512-i)})$$

for i=257 to 511

- Digital Front End (DFE) and Analogue Front End (AFE)

The digital front end and analogue front end of the adaptively duplexed modem is highlighted in the shaded region in Figure 1 and Figure 2. Due to the bandwidth changes of the upstream and downstreams signals, all the digital and analogue filters in this shaded region should posses the ability for adaptation.

For all the digital filters, the filter coefficients for each duplexing option have to be computed offline. If the implementation of the DFE is using DSP, the impact of the change from the adaptation of the upstream and downstream bandwidth is minimal. Different filter coefficients can be directly loaded from the memory.

For hardware implementation of the digital filters, a set of filter bank can be used. The signal to be transmitted can be switched to the appropriate filter in the filter bank by some programmable switch. Similar method can be applied to the analogue filters. A filter bank that includes all the possible analogue filters can be implemented. By switching, the signal can be appropriately filtered.

Spectral Compatible Opertaion of the Adaptively Duplexed DSL System

Coexistence with other DSL systems deployed in the copper network is very important issue for operators and regulators. In particular, spectral compatibility with existing systems becomes a necessity in the design of new systems. Spectrally compatible systems are those that can operate within the same cable binder without affecting each other's performance, for instance, by introducing near-end crosstalk.

To realize the spectrally compatible operation of the adaptively duplexed DSL system, several important factors has to be considered to avoid near-end crosstalk:

- Minimum bandwidth allocation rule. For example, when the DSL user is browsing website, upstream data rate can be low as few kilo bits per second. To avoid producing near-end crosstalk to other DSL modems, only necessary bandwidth is allocated to this upstream transmitter.
- Priority of the spectral allocation algorithm. Each DSL modem should have some basic allocation of the bandwidth. The priority of the extra bandwidth is lower.
- Transmission power in the extra bandwidth for certain has to be refrained depending on the line conditions. An algorithm detecting the noise environment is to be developed.
- Synchronization of all the DSL modems in the same cable bundle. This way, the near-end crosstalk can be minimized. [TBD]

ADAPTIVE DUPLEXING, CROSSTALK NOISE MINIMIZATION AND TRANSMISSION POWER REDUCTION FOR DIGITAL SUBSCRIBER LOOPS

Xianbin Wang, STMicroelectronics

Juen 8, 2001

Abstract

An adaptively duplexed DSL system is proposed in this disclosure. With the proposed technique, the DSL duplexing ratio, which is ratio between the upstream and downstream bandwidth, can be varied according to different applications. The architecture of the DSL modems that support the DSL systems with variable duplex ratios is also established. To optimize the performance of the DSL modems in the same cable bundle, near-end crosstalk noise (NEXT) is minimized by changing the number of the DMT subcarriers used for transmission when the bit load of the data stream to be transmitted is less than the capacity of the modem. The power consumption of the line driver can also be reduced significantly by the proposed NEXT minimization algorithm. The NEXT minimization and power reduction algorithm in this disclosure can be both applied to standard compliant modems and the adaptively duplexed DSL modems proposed in this disclosure.

Field of the invention

This invention relates to digital subscriber loop (DSL) system and more particularly to optimization of duplexing, near-end crosstalk noise and power consumption of the line driver for the DSL systems.

Background of the Invention

With the advent of inexpensive computers, the demand for residential broadband services has been increasing due to the widespread use of computers and the rapid development of computer networks. As a result, various Digital Subscriber Line (DSL) services have been proposed to make full deployment of the existing copper loop plant for the global information highway. DSL includes a large family, such as asymmetrical DSL (ADSL), high data rate DSL (HDSL), very high data rate DSL (VDSL) and so on, which forms a family loosely called *x-type digital subscriber line* (xDSL) technologies, where *x* stands for one of several letters of the alphabet.

Duplexing Ratio of the DSL System. The current duplexing ratio for certain DSL modem is fixed. The duplexing method determines how the overall bandwidth of a physical link is shared between the upstream and downstream transmission directions. For example, the bandwidth of ADSL

link is asymmetrically duplexed, with more bandwidth allocated to downstream. The basic assumption for ADSL is that ADSL user is mainly receiving data from Central Office (CO) all the time. While asymmetrical DSL is likely to be the most attractive option for casual Internet users, Symmetrical DSL (SDSL) is the most popular with businesses and teleworkers. SDSL meets the requirements of these segments, because this enables workers to send and receive large files from corporate servers with high speed in both directions. As the business and teleworker segments are predicted to be early adopters of DSL services, SDSL is an important offering. However, the duplexing ratios for both ADSL and SDSL are unchanged and do not account for the type of the application and bit rates of the DSL upstream and downstream signals.

An important fact is that different DSL duplexing ratios may be desired by the same user for different DSL applications. For example, when a video conference application is activated through a DSL link, a symmetrical link is optimal. However, an asymmetrical link is desired when an upload application is launched at a later time. It is to be noted here that the high data rate direction is not necessarily the downstream direction. And the duplexing ratio between upstream and downstream bandwidth can be varied on an application basis.

Obviously, with the current fixed duplexing technique, certain users may use one application for most of the time with an unfavourable

duplexing ratio. It would be significant if the DSL duplexing can be adapted for this application. Unfortunately, all the DSL systems available today cannot provide such kind of service in spite of the need to optimize the duplexing of the DSL link.

An adaptively duplexed DSL system is proposed in this disclosure. To implement DSL modems which can provide an adaptively duplexed link and operate such DSL systems cost effectively, the following factors have to be taken into account during the system design process:

- The design of digital signal processing (DSP) blocks in the DSL modems to meet the requirement of different bit rate for downstream and upstream due to the changes of duplexing ratio. The differences between these two data streams can be substantially large and the bit rate of the upstream can be much higher than downstream to meet some uploading applications.

- The digital front end (DFE) and analogue front end (AFE) of the modems has to be changed correspondingly with the bandwidth changes of the downstream and uptream.

- The spectrally compatible operation of adaptively duplexed DSL systems in the same cable bundle must be assured. As the bandwidth of the upstream and downstream can be substantially different with existing ADSL, near-end crosstalk may be generated

for some existing DSL modem in the same cable when the duplexing is to be adapted for a certain DSL user. Therefore, to avoid giving other users a large amount of crosstalk noise, each individual modem with adapted duplexing ratio has to be aware of the bandwidth in use. And this modem also has to monitor the crosstalk noise to other users. In case of serious bandwidth impairment by the extra bandwidth from duplexing adaptation, there should be some rule that the user can reduce the crosstalk by giving up the extra bandwidth. Therefore, the bandwidth changes resulting from the adaptation of duplexing ratio may have to be reset to standard-compliant values.

These problems will be discussed in details in the following sections.

Minimization of Corsstalk noise for DSL modems in the same cable bundle. Crosstalk is noise on a phone line that is caused by electromagnetic radiation of other phone lines in close proximity, in practice within in the same cable. The term was originally coined to indicate the presence in a telephone receiver of unwanted speech sounds from another telephone conversation. The methods which were developed for computing and measuring quantitatively were soon found to be useful in studying interference between non-telephone circuits. Therefore, the

term has been gradually broadened to apply to interference between any kinds of communications circuits. This kind of noise includes near-end crosstalk (NEXT) and far-end crosstalk (FEXT). It is generally accepted that the NEXT is the major interference for DSL since the FEXT noise will pass through the entire DSL loop and the propagation loss generally is very large. Therefore, minimization of near-end crosstalk noise becomes very important when DSL services are offered on the different loops in the same cable. Any reduction in near-end crosstalk noise will improve the DSL system error rate performance or increase the loop throughput.

In current DSL standards, idle ATM cells are inserted to fill up all the data frames when the bit rate of the transmitted signal is smaller than the throughput of the DSL link (both upstream and downstream). In some extreme situations, there can be even no data to be transmitted and the transmitter becomes merely a source of crosstalk noise. If we can intelligently select the minimum number of the subcarriers used for the Digital Multi-tone (DMT) signals, the crosstalk noise to other users, especially NEXT, can be significantly reduced.

Reduction of the Power consumption for DSL line driver. Power consumption is also very important factor in DSL modem design for both CPE and CO. One reason is that the more power is transmitted, the more

crosstalk noise will be coupled to other DSL users in the same cable. On the other hand, when USB interface is used for an external modem at CPE side, the power consumption of the modem is limited by the USB standard. For CPE, power consumption may also become one important problem for Laptops as the capacity of the battery is limited. For central office, as many DSL line cards are installed in a very limited space, any reduction in power consumption will relax the stringent requirement for heat dissipation.

In the proposed NEXT noise minimization technique, the usage of the upstream and downstream bandwidth in terms of the number of DMT subcarriers used is controlled according to the bit rates of the data streams in the two directions. By doing this, the power consumption of the line driver is substantially reduced. As for most applications nowadays, the bit rate of the signal to be transmitted is far below the DSL modem capacity. The use of additional bandwidth by the ATM idle cells will lead to NEXT noise to other users in the same cable bundle and also increase the power consumption for both of the line drivers at CO and CPE side. The relationship between the number of subcarriers used in the DSL modems and the amount of the reduction in power consumption is also determined in the following sections. As the available network accessing speed is still very low for most of the residential users, which is limited by the whole

network, the power consumption can be reduced significantly with this proposal.

Application Area

Adaptively duplexed DSL. With the adaptively duplexed DSL, the upstream and downstream data rates are substantially different for different applications. The duplexing techniques can be set according to DSL users when different applications are launched or adapted on-line by some system management rule. Some application examples are:

- Internet and remote LAN access,
- Home office applications,
- File transfer (Upload and Download),
- Video Conferencing,
- Interactive games,
- Home shopping.

NEXT minimization and power Reduction. The methods of minimization of the near-end crosstalk noise and power reduction are general techniques which can be used both with any ITU and ANSI

standard modems or adaptively duplex DSL system proposed in this disclosure.

Modem Architecture of Adaptively Duplexed DSL System

Figure 1 and 2 show the functional blocks and interfaces of the ATU-R and ATU-C transmitters for the adaptively duplexed DSL modems. The ATU-R transmitter is similar to ATU-C transmitter but without the OAM (Operation, Administration and Maintenance) path. We can see an important characteristic of this system is that the ATU-C and ATU-R transmitters are symmetrical in the sense that a 512-point IFFT is employed. The modifications from conventional DSL transmitter are also in the digital and analogue processing blocks, which is highlighted in the shaded region in Figure 1 and 2.

With the modems depicted in Figure 1 and 2, a different duplexing method can be implemented on the same DSL link. Theoretically, duplexing ratio between the upstream and downstream bandwidth can be set arbitrarily. However, only a limited number of options can be implemented due to the cost and complexity of modems. A sample of the duplexing options is listed in Table 1.

It is to be noted that some efficient IFFT/FFT algorithms with only half of the points might be used to reduce the system complexity. In this

case, a 256-point complex IFFT/FFT will be used and the Hermittian symmetry operation is eliminated. The modifications to 256-point IFFT for the adaptively duplexed DSL is very simple---just set the inputs to zero for the subcarriers that are not in use. We limit our discussion here to 512-point IFFT with real output, as it is DSL standards compliant.

Another important issue to be noted here is that no matter what kind of bit rate we have, the upstream and downstream links should be kept during the adaptation process. In case of no data to be transmitted, a minimum number of idle ATM cells should be inserted to keep the data synchronization of this specific link. That is, the minimum of the subcarriers for upstream and downstream should be greater than zero. For example, the minimum of subcarriers is 8 for upstream and downstream links in Table 1. Therefore, the rate of the idle ATM cells will depend on the capacity of these minimum subcarriers when there is no input data.

Upstream (Subcarriers)	8	32	64	96	128	160	192	224	248
Downstream (Subcarriers)	248	224	192	160	128	96	64	32	8

Table 1. A sample duplexing options for DSL upstream and downstream.

- *Modulation by the IDFT for a given duplex ratio.*

The modulating transformation defines the relationship between the real time domain samples x_n and the IDFT input Z_i'is

$$x_n = \sum_{i=0}^{511} \exp\left(\frac{j\pi ni}{256}\right) Z_i' \tag{1}$$

n=0, ..., 512.

For ATU-R and ATU-C transmitters, Z_i' are generated with different methods as we discuss below.

<u>*ATU-R Transmitter.*</u> Assume $N_{upstream}$ subcarriers (1, 2, ..., $N_{upstream}$) are allocated for the transmission of upstream signal for a given duplex ratio. The complex values from constellation encoder and gain scaling for the *i*-th subcarrier is Z_i. In order to generate real output x_n from IDFT, Z_i is first mapped to Z_i' with

$$Z_i' = \begin{cases} 0 & i = 0 \\ Z_i & 1 \le i \le N_{upstream} \\ 0 & N_{upstream} < i \le 256 \end{cases} \tag{2}$$

The vector Z_i' shall be augmented such that Z_i' has the Hermitian symmetry. That is

$$Z_i' = conj\left(Z'_{(512-i)}\right) \tag{3}$$

for i=257 to 511

ATU-C Transmitter. Assume $N_{downstream}$ subcarriers ($N_{upstream}+1$, $N_{upstream}+2$, ……, $N_{upstream}+N_{downstream}$, and $N_{upstream}+N_{downstream} \leq 255$) are allocated for the transmission of downstream signal for a given duplex ratio. The complex values from constellation encoder and gain scaling for the *i*-th subcarrier is Z_i. In order to generate real output x_n from IDFT, Z_i is first mapped to Z_i' with

$$Z_i' = \begin{cases} 0 & i = 0 \\ Z_i & N_{upstream}+1 \leq i \leq N_{upstream}+N_{downstream} \\ 0 & i = 256 \end{cases} \tag{4}$$

The vector Z_i' shall be augmented such that the Z_i' has Hermitian symmetry. That is

$$Z_i' = conj\left(Z'_{(512-i)}\right) \tag{5}$$

for *i*=257 to 511

- *Digital Front End (DFE) and Analogue Front End (AFE)*

The digital front end and analogue front end of the adaptively duplexed modem is highlighted in the shaded region in Figure 1 and Figure 2. Due to the bandwidth changes of the upstream and downstreams signals, all the digital and analogue filters in this shaded region should posess the ability for adaptation.

For all the digital filters, the filter coefficients for each duplexing option have to be computed offline. If the implementation of the DFE is using DSP, the impact of the change from the adaptation of the upstream

and downstream bandwidth is minimal. Different filter coefficients can be directly loaded from the memory.

For hardware implementation of the digital filters, a set of filter banks can be used. The signal to be transmitted can be switched to the appropriate filter in the filter bank by some programmable switch. Similar method can be applied to the analogue filters. A filter bank that includes all the possible analogue filters can be implemented. By switching, the signal can be appropriately filtered.

- *Training of echo canceller for Adaptively Duplexed DSL modem.*

In some DSL standards, the overlapping spectrum mode of upstream and downstream signals is used. Basically, upstream bandwidth and downstream bandwidth are overlapped and the upstream bandwidth will be part of the downstream bandwidth. In this case, an echo canceller is used in the DSL modem receiver to eliminate the echoes from its own transmitter since these echoes fall in the frequency band of the receiving signal. To comply with the changes from the adaptation of the duplexing ratio, the training DMT symbols for the echo canceller should have the widest bandwidth among all the duplexing options during the initialization process. For example, if the largest bandwidth for upstream signal is Table 1 is 248 subcarriers, the training sequence for this modem will have the bandwidth of 248 subcarriers.

Near-end Crosstalk noise (NEXT) Minimization

Coexistence with other DSL systems deployed in the copper network is very important issue for operators and regulators. In particular, spectral compatibility with existing systems becomes a necessity in the design of new systems. Spectrally compatible systems are those that can operate within the same cable binder without affecting each other's performance, for instance, by introducing near-end crosstalk. Particularly for adaptively duplexed DSL, extra bandwidth might be occupied by either the upstream signal or downstream signal, compared with standard ADSL spectrum. Therefore, there is a need to determine a rule for the adaptively duplexed modems giving up the extra bandwidth when their bandwidth utilization is interfering with other existing DSL modems.

NEXT noise minimization. It is well known that the performance of the DSL modems is generally limited crosstalk noise by other modems that are connected to the other loops in the same cable binder. The crosstalk phenomenon can be modelled using two terms, namely the near-end cross talk (NEXT) and the far-end crosstalk (FEXT). The NEXT and FEXT terms are illustrated in Figure 3.

Crosstalk noise that occurs when a receiver on a disturbed pair is located at the same end of the cable as the transmitter of an interferer is called Near-End Crosstalk (NEXT). Crosstalk noise that occurs when a

receiver on a disturbed pair is located at the other end of cable as the transmitter of the disturbing pair is called Far-End Crosstalk (FEXT). NEXT noise is generally much greater than FEXT noise.

In order to improve the performance of the DSL modems, one primary objective of the modem designers should be the minimization of the crosstalk in the cable binder, especially the NEXT noise. For example, near end crosstalk is minimised in G.Lite and G.DMT by the separation of the upstream and downstream bandwidth. To optimize the performance of the DSL system, several important factors have to be considered to avoid near-end crosstalk:

- Minimum bandwidth allocation. For example, when the DSL user is browsing a website, upstream data rate can be low as few kilo bits per second. To avoid generating near-end crosstalk for other DSL modems, only necessary subcarriers are allocated in the upstream signal. Other subcarriers can be simply switched off by setting the corresponding inputs to the IFFT to zeros.
- Minimization of the near-end crosstalk noise. This can be done by minimizing the overlapping spectrum which mainly reduces the NEXT noise as we'll discuss later.

To implement these ideas when establishing a new DSL link, the following procedure can be used: 1) Determine the bit rate of the new link. For the ATM link, the idle cells have to be removed. 2) Calculate the optimal duplexing ratio based on the upstream and downstream bit rate. 3) Minimization of the near-end crosstalk noise by minimizing the overlapping spectrum among all the DSL loops.

1) Determination of the bit rate.

The idle ATM cells removal process permits the identification of ATM cell boundaries in the payload and discarding of the idle cells. It uses the HEC field in the cell header. Idle cell removal shall be performed using a coding law checking the HEC field in the cell header according to the algorithm described in ITU Recommendation I.432. The idle cell removal state machine is shown in Figure 4. The details of the state diagram are described below:

- *In the HUNT state, the ATM delineation process is performed by checking bit by bit for the correct HEC. Once such an agreement is found, it is assumed that one header has been found, and the method enters the PRESYNC state. When byte boundaries are available, the cell delineation process may be performed byte by byte.*
- *In the PRESYNC state, the delineation process is performed by checking cell by cell for the correct HEC. The process repeats until the correct HEC has*

been confirmed DELTA times consecutively. If an incorrect HEC is found, the process returns to the HUNT state.

- *In the SYNC state, idle cells will be discarded by checking the header of each cell. The cell delineation will be assumed to be lost if an incorrect HEC is obtained ALPHA times consecutively.*

In ITU-T I.432, the use of the values of ALPHA and DELTA are suggested as 7 and 6, respectively. The operation procedure of idle cell removal process can be found in Figure 5.

2) Calculation of the duplexing ratio.

Once all the idle cells are discarded, the desired duplex ratio for the new link can be determined as:

$$D = \frac{BitRate_{upstream}}{BitRate_{Downstream}} \quad (6)$$

Given the determined duplex ratio, an appropriate duplexing scheme can be selected from the option list like the one in Table 1. It is to be noted here that due to the implementation cost of digital and analogue filter banks, the number of the duplexing options is limited. Therefore, only a sub-optimal duplex scheme can be used at most of the times.

3) Minimization of the near-end crosstalk noise.

After choosing the duplex scheme, the maximum bit rates can be supported by the upstream and downstream bandwidth can be calculated (The bit map should be available at this time). The real upstream and downstream bit rates will generally be much smaller than their corresponding maximum throughputs. Therefore, by using different parts of the available bandwidth of upstream and downstream, the overlapping bandwidth for NEXT noise can be minimized within the same cable. This idea is illustrated in Figure 6 for the CPE receiver. It is to be noted here that the meaning of "overlapping bandwidth" is the bandwidth that is responsible for NEXT, as illustrated in Figure 7 and 8 for overlapping and non-overlapping modes of DSL systems. The shaded bandwidth is the necessary bandwidth to support the downstream bit rate. As the available downstream bandwidth is wider than the shaded region, the NEXT noise in this shaded region can be minimized by changing the position of the shaded region. The shaded bandwidth window can be moved from the lower end to the higher end of the downstream bandwidth. The NEXT noise at each position can be computed with the method we'll discuss in the following parts. Comparing the NEXT noise at different positions, the position of the shaded region with minimum NEXT noise will be selected.

Before we move to the details of the NEXT minimization, NEXT noise has to be computed. This can be done using two different methods.

Determination of NEXT noise by analytical method. The NEXT crosstalk noise from n identical disturbing sources were modelled with empirical coupling transfer functions of the following forms, respectively[1],

$$PSD_{NEXT}(f_k) = PSD_{disturber}(f_k) \times X_N \times n^{0.6} \times f^{\frac{3}{2}} \quad (7)$$

where $X_N = 8.536 \times 10^{-15}$, n =number of disturbers, f_k is the frequency in Hz at k-th subcarrier, and $PSD_{disturber}$ is the power spectrum of the interfering system. However, it is very common that different disturbers co-exist in the same cable. To combine the crosstalk contributions from different disturbers, the following expression is used to calculate the NEXT due to the combination sources[1].

$$PSD_{NEXT\_TOTAL}(f_k) = \left(\sum_{i}^{M} \left(PSD_{i,disturber}(f_k, n_i) \right)^{\frac{1}{0.6}} \right)^{0.6} \quad (8)$$

where M is the number of the types of the disturbers and n_i is the number of the disturbing sources for each type. For example, consider the case of two sources of NEXT at a given receiver. In this case there are n_1 disturber systems of spectrum $S_1(f)$ and n_2 disturber systems of $S_2(f)$. The combined NEXT is expressed as[1]:

$$PSD_{NEXT\_TOTAL}(f_k) = \left(\left(S_1(f_k, n_1) \right)^{\frac{1}{0.6}} + \left(S_2(f_k, n_2) \right)^{\frac{1}{0.6}} \right)^{0.6} \quad (9)$$

Determination of NEXT noise by estimation method. To compute the near-end crosstalk noise with equation (9), the duplexing details of all the

DSL loops in the same cable should be available to the new initialised modem. However, this requirement cannot be met sometimes, for example, at CPE side or for the present standard compliant systems. In this case, the near-end crosstalk noise can simply estimated using the silent symbols during the initialization process. The corresponding equation now becomes[1]:

$$PSD_{NEXT\_TOTAL}(f_k) = \frac{1}{L\sqrt{N}} \sum_{i=0}^{L-1} \sum_{n=0}^{N-1} r_i(n).\exp\left(\frac{j2\pi kn}{N}\right) \tag{10}$$

where L is the total number of the silent DMT symbols for the NEXT noise estimation and i is the index of the subcarriers for NEXT estimation. $r_i(n)$ is the n-th received sample for the i-th DMT symbol. It is to be noted here that this estimation result in fact is the combination of NEXT, FEXT and additive white Gaussian noise. However, as the NEXT is the major interference, the above estimation can be approximately regarded as near-end crosstalk noise.

Therefore, to minimize the next end crosstalk for the new initialized loop in the same cable bundle, the following procedures can be employed

1) Find the number of subcarriers needed to support the upstream and downstream when sliding the bandwidth window. This number

should be different at different window positions due to the fact that different numbers of bits can be supported in DSL system.

2) Calculate the overlapping cost functions and slide the needed bandwidth widow (shaded bandwidth) through the available bandwidth. This is indicated in Figure 3. The overlapping cost function is defined as:

$$G(i) = \frac{1}{k_1(i) - k_2(i)} \sum_{k=k_1(i)}^{k_2(i)} \frac{4\exp\left(-\frac{3E_s(k)}{4(M-1)\sigma_k^{\ 2}}\right)}{\sqrt{\frac{3E_s(k)}{2(M-1)\sigma_k^{\ 2}}} \cdot \sqrt{2\pi}} \tag{11}$$

where k_1 and k_2 are the beginning and ending point of the shaded bandwidth in terms of subcarrier index. $E_s(k)$ and $\sigma_k^{\ 2} = PSD_{NEXT\_TOTOAL}(f_k)$ are the symbol energy and NEXT noise variance for the k-th subcarrier during the training process. It is to be noted here k_1 and k_2 will depend on the position index i.

Definition of the NEXT noise Overlapping Cost Function

Equation(11) is the in fact the bit error rate of the DSL link to be optimized. By minimizing equation(11), the DSL link will have optimal performance. Therefore, the bit error rate of the DSL system has to be determined first. Each of the DMT subcarriers can be viewed as an independent QAM modulated single carrier. Hence we start with an uncoded QAM system over an ISI-free, Gaussian channel. For *M*-ary *QAM* transmissions, the symbol error rate (*SER*) can be approximated by,

$$P_s = N_e \cdot Q\left(\frac{d}{\sigma}\right) \tag{12}$$

where

$$N_e = \frac{1}{M}\sum_{m=0}^{M-1} N_m$$

(13)

is the average nearest neighbors with N_m is the number of the nearest neighbors for the m-th constellation point. $2d$ is the minimum distance between adjacent constellation points. For a QAM system with large constellation size, we can assume all the constellation points have four adjacent signal points around. Apparently, this is not valid for the signal points on the edge of the constellation, where they have only 2 or 3 neighbors. However, Equation (12) with $N_e = 4$ can be looked as an upper bound of the *SER*. This upper bound is tight for large constellation where most of the signal points are inner points. For most of the DMT subcarriers, this approximation is accurate as the number of bits carried is fairly large, say, from 6 to 15 bits. As Gray encoding is employed in most of the QAM constellation mapping device, Equation (12) can also be regarded as bound for the BER. The average symbol energy of an M-ary QAM constellation with minimum distance $2d$ can be expressed as,

$$E_s = \frac{1}{6}(M-1)(2d)^2$$

(14)

Taking Equation (14) into Equation (12), the BER can be approximated by

$$P_b = N_e \cdot Q\left(\sqrt{\frac{3E_s}{2(M-1)\sigma^2}}\right)$$

(15)

where

$$Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \approx \frac{e^{-\frac{x^2}{2}}}{x\sqrt{2\pi}}.$$

(16)

Equation (15) can be approximated as:

$$P_b = N_e \cdot \frac{\exp\left(-\frac{3E_s}{4(M-1)\sigma^2}\right)}{\sqrt{\frac{3E_s}{2(M-1)\sigma^2}} \cdot \sqrt{2\pi}} \tag{17}$$

For large constellation size, the number of the neighboring constellation points can be approximately regarded as 4. With this in mind and averaging the BER over all subcarriers in use, the cost function can be defined as in Equation(11).

3) Minimization of the near-end crosstalk noise by choosing the minimum *G(i)*. The corresponding $k_1(i)$ and $k_2(i)$ represents the bandwidth with minimum NEXT noise.

Abandon of the extra bandwidth using a decision-directed NEXT estimation technique for Adaptively Duplexed DSL

It is very common that an adaptively duplexed DSL using extra bandwidth is initialized first. And other DSL users in the same cable are initiated later. In this case, it won't be surprise if there is any spectrum usage conflict in the sense that significant NEXT is produced.

To avoid this situation, the NEXT crosstalk noise from other users in the extra bandwith is monitored continuously by the modem using extra bandwidth, compared to conventional ADSL. When the NEXT changes substantially, the extra bandwidth has to be given up. The NEXT noise for the k-th subcarrier can be estimated as:

$$\sigma_k^2 = \frac{1}{L}\sum_{i=0}^{L-1}\left|\tilde{D}_k - D_k\right|^2 \qquad (18)$$

where L is the number of the DMT symbols used for NEXT estimation. $\tilde{D}_k$ and D_k are the demodulated output and correct decision for the k-th subcarrier.

Reduction of power consumption for DMT Systems

As discussed in the previous sections, only a minimum set of subcarriers will be assigned to upstream and downstream signals after NEXT noise is minimized. Minimization of the transmission bandwidth will lead to the reduction of the power consumption of the line driver.

The DMT signal samples in real form after the IFFT module can be expressed as:

$$s(n) = \frac{2}{\sqrt{N}} \sum_{k=1}^{(N/2)-1} g_k \left\{ a_k \cos\left(\frac{2\pi kn}{N}\right) + b_k \sin\left(\frac{2\pi kn}{N}\right) \right\}, \tag{19}$$

where $a_k - jb_k$ is the transmitted data for the k-th sub-carrier and N is the fast Fourier transform size of the DMT system, respectively. g_k is the transmission power control factor for the k-th subcarrier. The variance of the DMT signal can be easily determined as follows.

$$\sigma_s^2 = \frac{2}{N} \sum_{k=1}^{(N/2)-1} g_k^2 \left(a_k^2 + b_k^2\right), \tag{20}$$

However, if not all of subcarriers are used in the transmitter, the variance of the DMT signal becomes:

$$\sigma_s^2 = \frac{2}{N}\sum_{k=k_1}^{k_2} g_k^2\left(a_k^2 + b_k^2\right), \tag{21}$$

As the bit rate may vary significantly for different applications and the data rate across the network has bottlenecks, the proposed minimum bandwidth allocation algorithm will have a substantial effect on power consumption reduction. For example, if we assume the downstream bit rate is 500Kb/s, which typically not available as Internet accessing speed for most residential users, the power consumption can be reduction by approximately (6000-500)Kb/6000Kb=91.66%. For a downstream with a lower available accessing speed, this figure can still be higher.

Summary

In this disclosure, an adaptively duplexed DSL system is proposed. With this proposal, the duplex ratio, which is ratio between the upstream and downstream bandwidth, can be varied according to different applications. The architecture of the modems supported this DSL systems is also proposed. To optimize the performance of the DSL modems in the same cable bundle, the near-end crosstalk noise is minimized by intelligently change the bandwidth used for transmission when the bit rate for the transmission is less than the capacity of the modem. The transmission power consumption is also significantly reduced by the proposed algorithm

Claims

1. An adaptively duplexed DSL system is proposed. A modem structure to support this system is also established.
2. A bandwidth allocation algorithm which minimizes the near end crosstalk noise for the different DSL users in the same cable.
3. The proposed NEXT minimization algorithm can also reduce the power consumption of the DSL modem significantly.
4. In case of no data to be transmitted for DSL uplink or downlink, a minimum number of idle ATM cells will be inserted to keep the data synchronization of the DSL link.
5. A decision directed extra bandwidth abandon algorithm is proposed to handle the situation when there is severe NEXT noise for other DSL users caused by adaptively duplexed DSL.
6. As the special subset of the adaptively duplexed DSL, CPE of symmetrical DSL (with equal upstream and downstream data rate) is unlikely to interfere with existing standard-compliant CPE modems. This is because the CPE's which transmit in the G.Lite or G.DMT designated DS band are usually far enough away from each other, especially for North American users. That is, the merge point of the different twisted pairs into one cable is usually far away from each individual residential user. Due to propagation loss, the

symmetrically duplexed DSL CPE will probably cause no significant NEXT for other CPEs.

References

[1]. T1.417 (Spectrum Management for Loop Transmission Systems, American National Standard), Alliance for Telecommunications Industry Solutions (ATIS), Jan. 2001.

Figures:

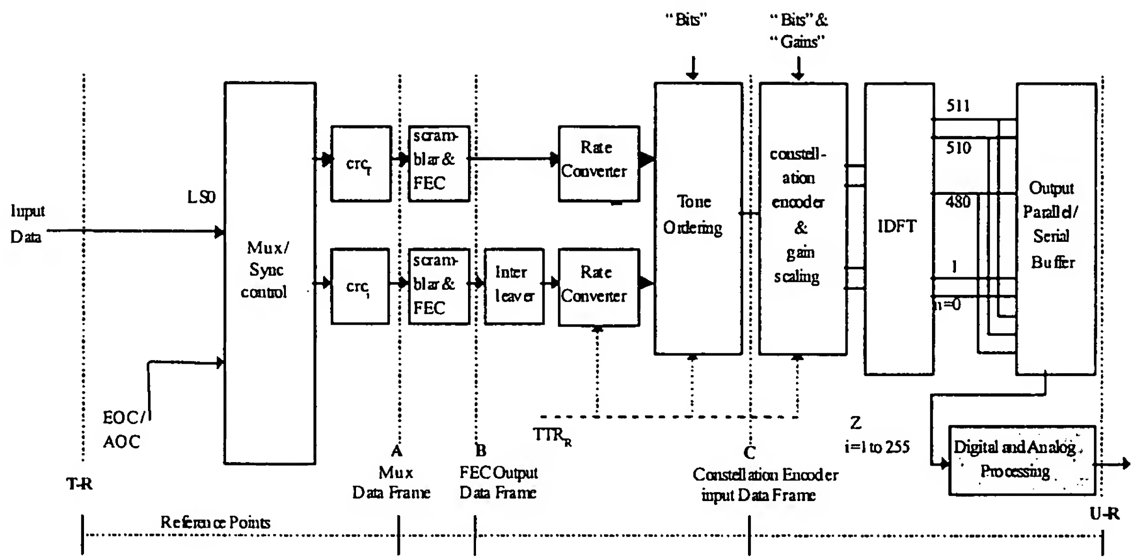

FIGURE.1 ATU-R TRANSMITTER MODEL

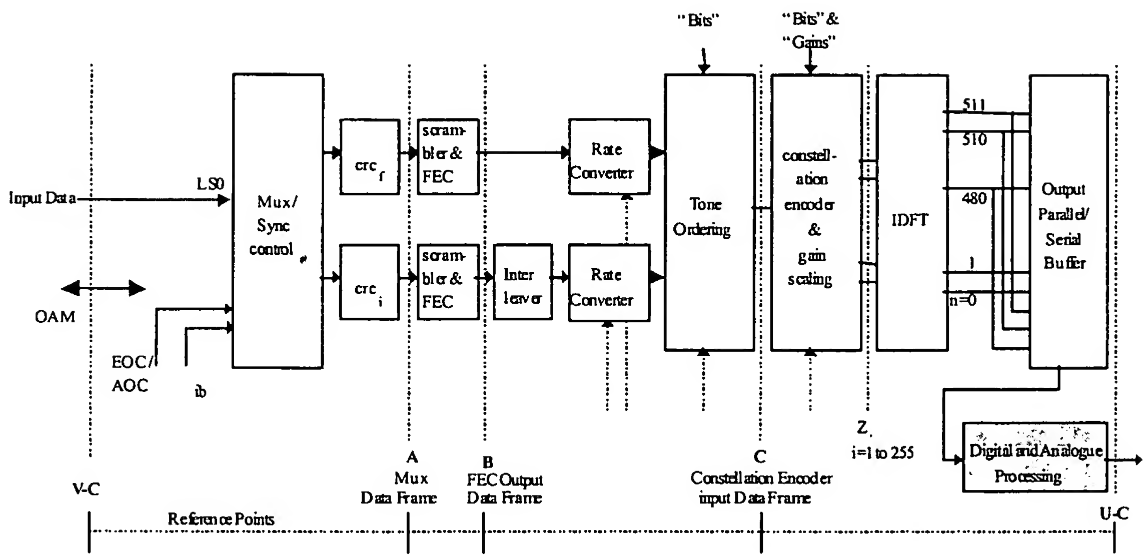

FIGURE 2 ATU-C TRANSMITTER MODEL

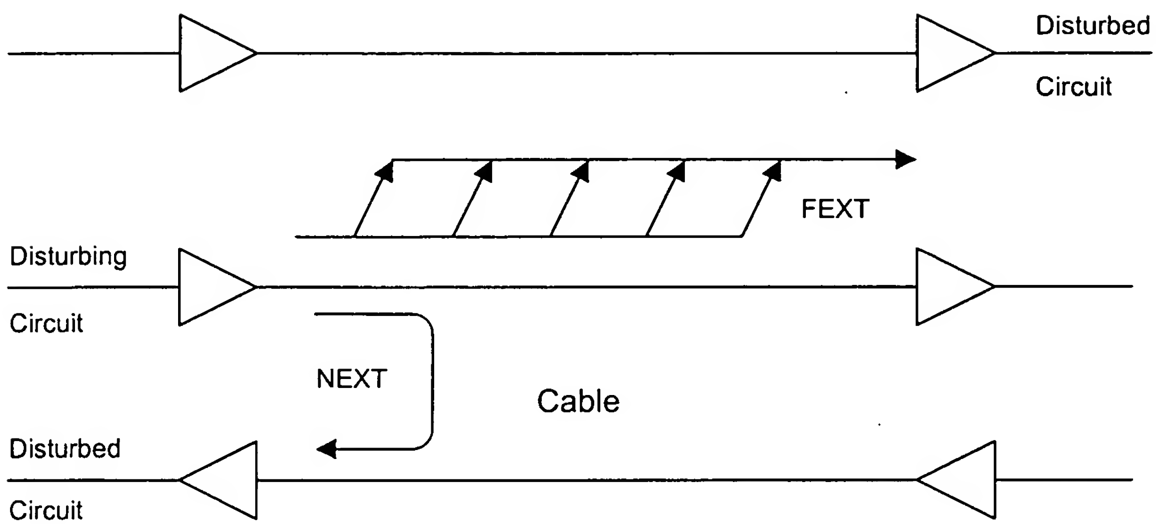

FIGURE 3. FAR-END CROSSTALK AND NEAR-END CROSSTALK COUPLING IN TYPICAL SUBSCRIBER LOOPS

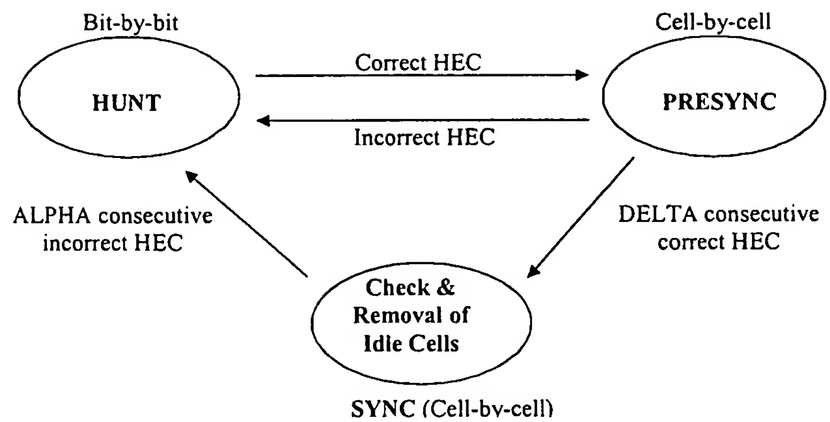

FIGURE 4 ATM IDLE CELLS REMOVAL STATE MACHINE

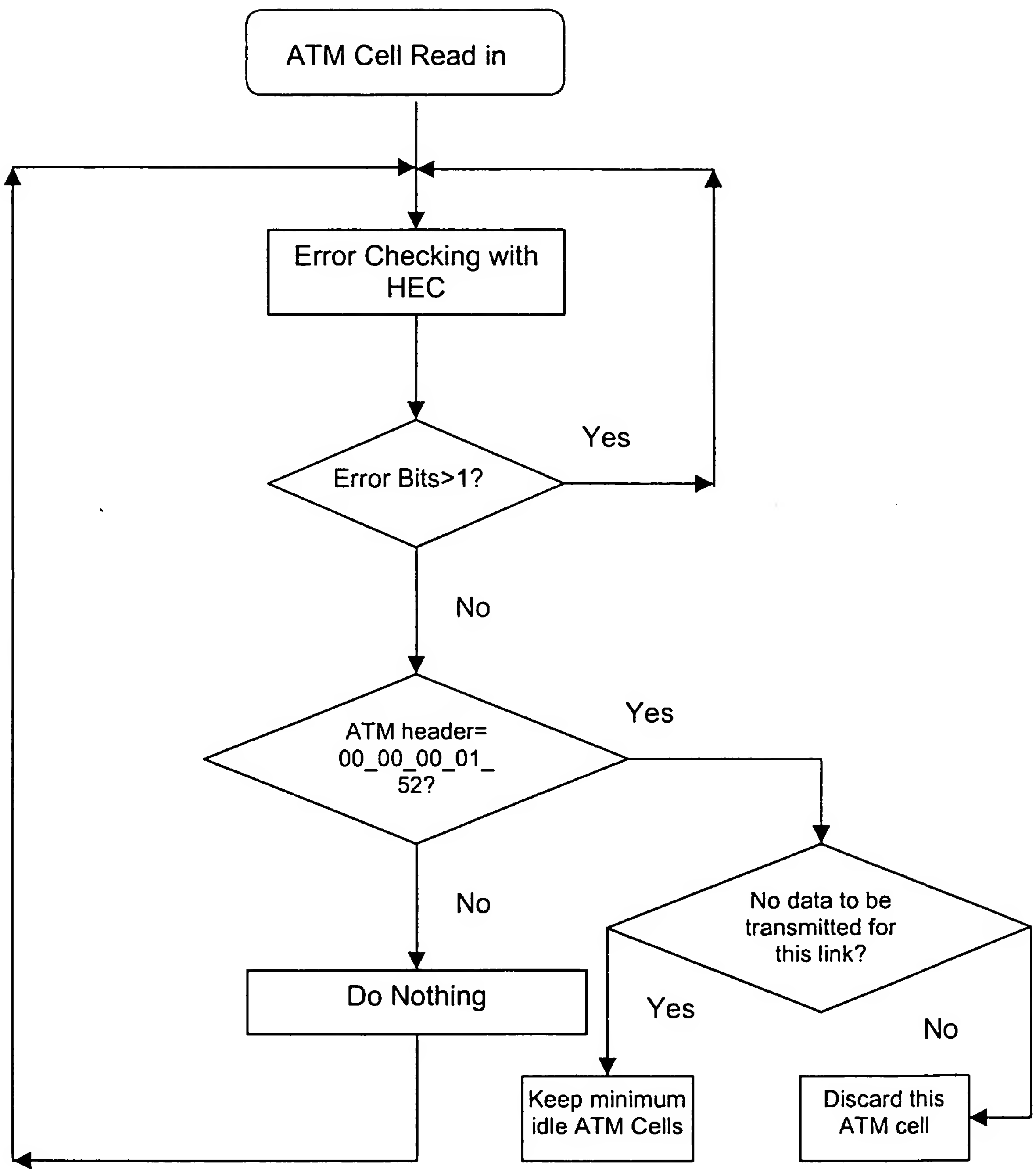

FIGURE 5. ATM IDLE CELL REMOVAL PROCEDURE.

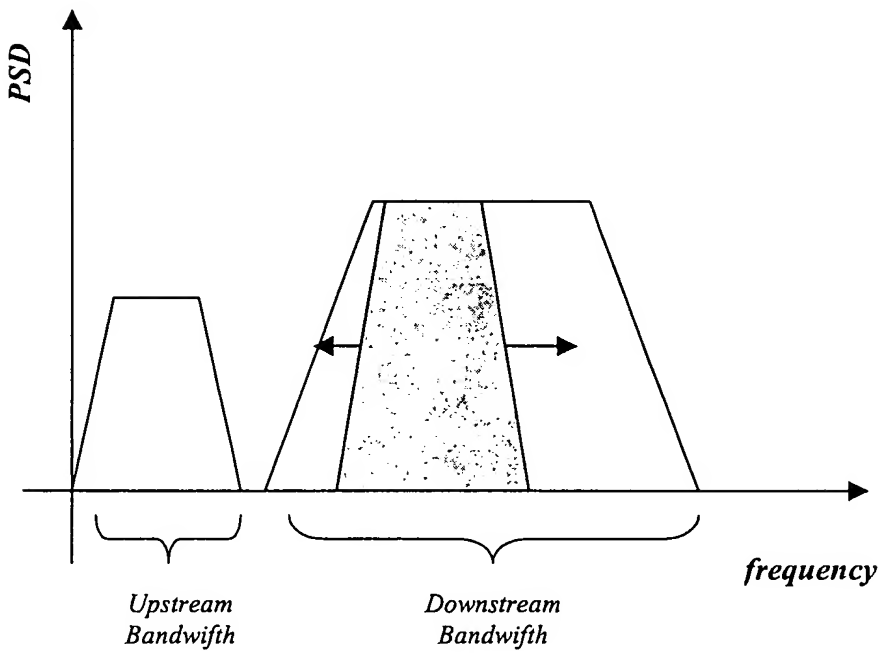

FIGURE 6. MINIMIZATION OF NEXT NOISE FOR THE CPE RECEIVER BY SLIDING WINDOW METHOD. THE SHADED REGION IS THE NEEDED BANDWIDTH TO SUPPORT THE DOWNSTREAM BIT RATE.

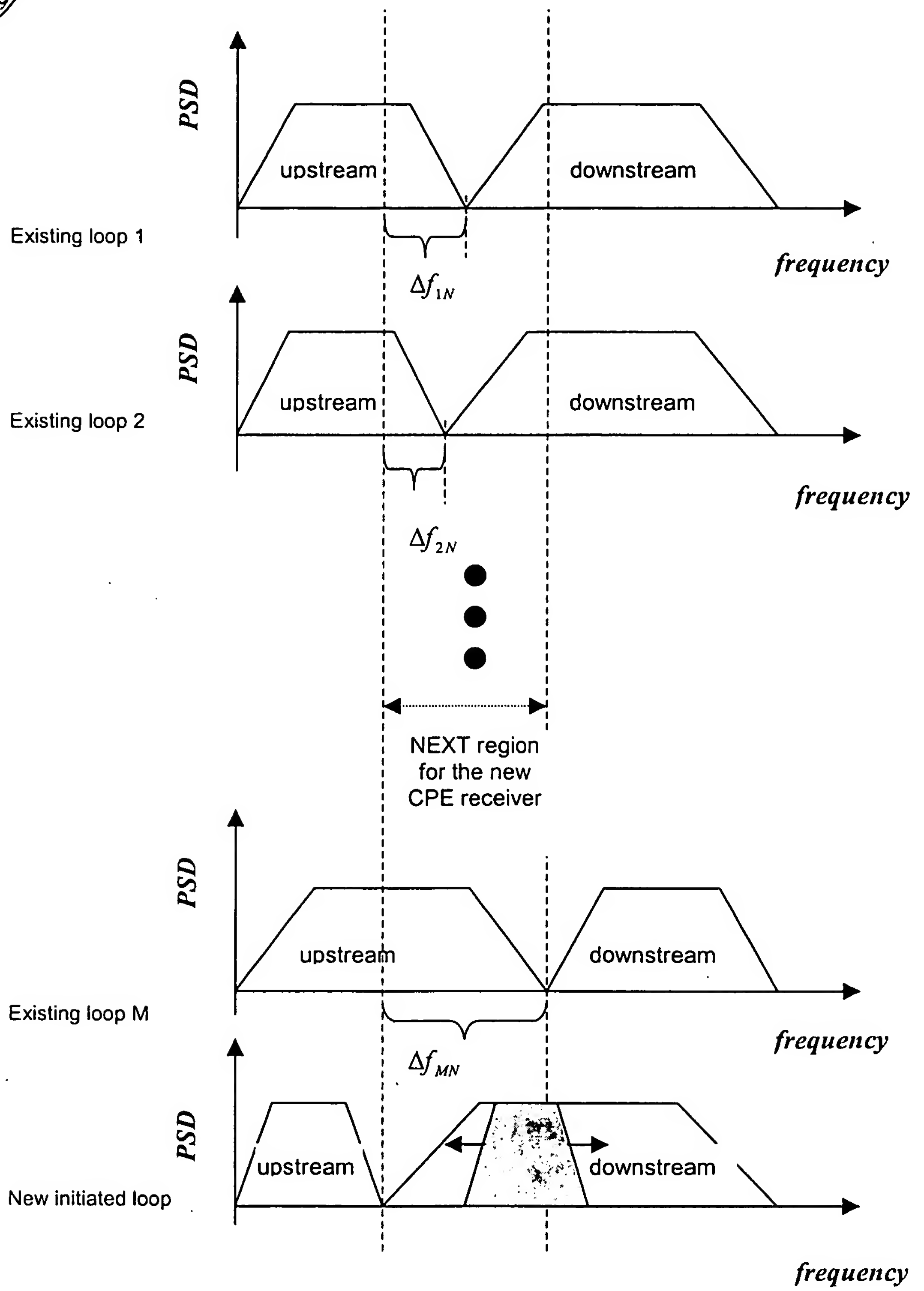

FIGURE 7. NON-OVERLAPPED SYSTEM.

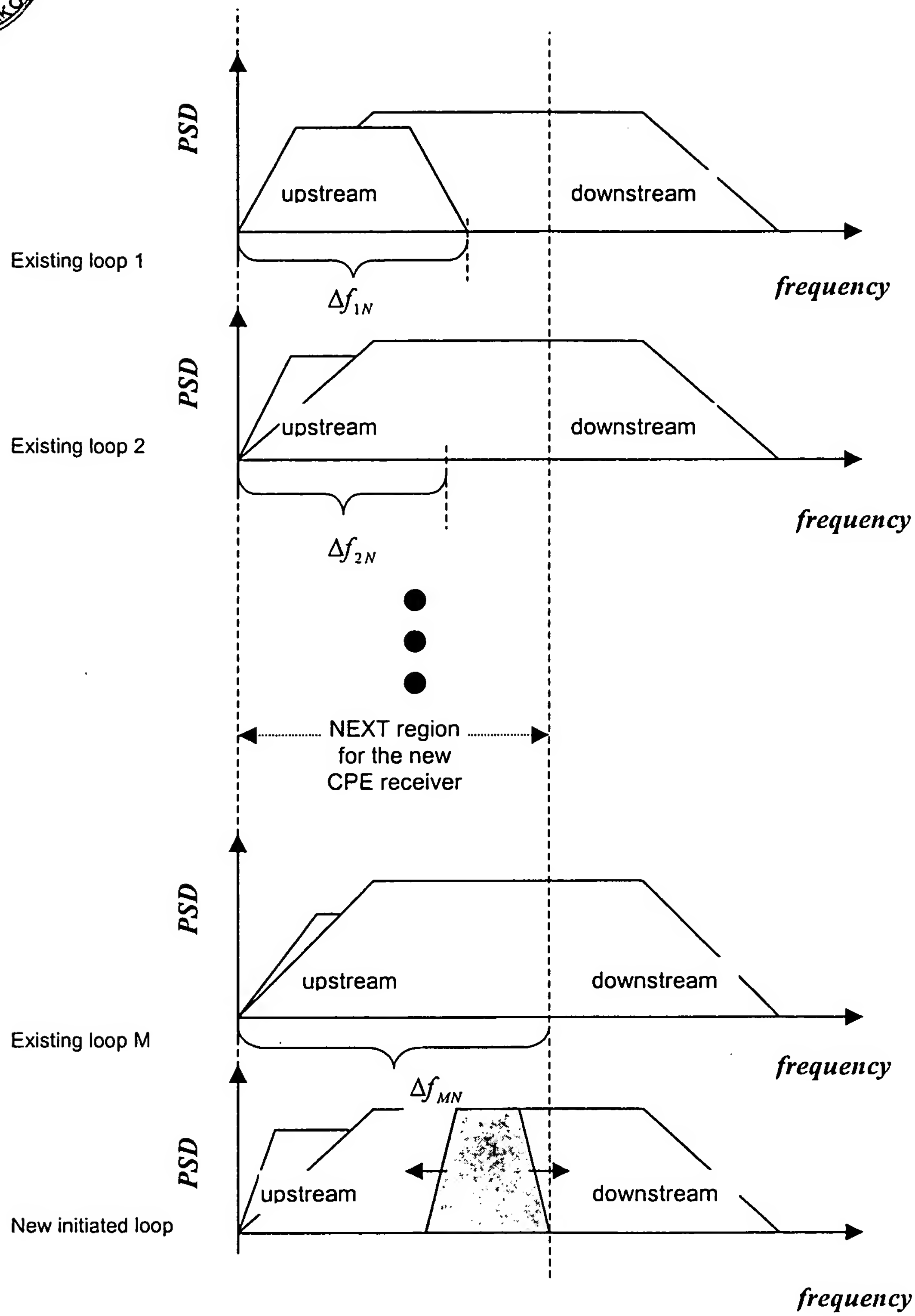

FIGURE 8. OVERLAPPED SYSTEM.

OIPE IAP46
SEP 21 2005
PATENT & TRADEMARK OFFICE

FC

Jenkens & Gilchrist
A PROFESSIONAL CORPORATION

1445 Ross Avenue
Suite 3200
Dallas, Texas 75202

(214) 855-4500
TELECOPIER (214) 855-4300

www.jenkens.com

AUSTIN, TEXAS
(512) 499-3800

HOUSTON, TEXAS
(713) 951-3300

LOS ANGELES, CALIFORNIA
(310) 820-8800

SAN ANTONIO, TEXAS
(210) 246-5000

WASHINGTON, D.C.
(202) 326-1500

AFFILIATE OFFICE
CHICAGO, ILLINOIS
(312) 425-3900

Andre M. Szuwalski
(214) 855-4795
aszuwalski@jenkens.com

November 20, 2001

Xianbin Wang
STMicroelectronics, Inc.
16 Fitzgerald Road, Suite 300
Nepean, Ontario K2H 8R6
CANADA

VIA FEDERAL EXPRESS

Re: Patent application entitled "Method and Apparatus for Application Driven Adaptive Duplexing of Digital Subscriber Loops"
Your Ref. No.: 00-OT-080
Our Ref. No.: 28940-116

Dear Xianbin:

Enclosed is a first draft of a patent application covering the above-identified invention. Please review this application to determine if it accurately and adequately describes your invention, noting on the enclosed draft any comments or suggestions you may have.

After you have completed your review, please return the draft to me. The application will then be revised and placed in condition for filing in the Patent and Trademark Office, and the original will be transmitted to you for execution.

Very truly yours,

Andy

Andre M. Szuwalski

Enclosure

cc: Robert McCutcheon (w/ encl)

Dallas2 845447 v 1, 28940.00116

Exhibit B

Jenkens & Gilchrist
A PROFESSIONAL CORPORATION

1445 Ross Avenue
Suite 3200
Dallas, Texas 75202

(214) 855-4500
TELECOPIER (214) 855-4300

www.jenkens.com

AUSTIN, TEXAS
(512) 499-3800

HOUSTON, TEXAS
(713) 951-3300

LOS ANGELES, CALIFORNIA
(310) 820-8800

SAN ANTONIO, TEXAS
(210) 246-5000

WASHINGTON, D.C.
(202) 326-1500

AFFILIATE OFFICE
CHICAGO, ILLINOIS
(312) 425-3900

Andre M. Szuwalski
(214) 855-4795
aszuwalski@jenkens.com

December 5, 2001

Xianbin Wang
STMicroelectronics, Inc.
16 Fitzgerald Road, Suite 300
Nepean, Ontario K2H 8R6
CANADA

VIA FEDERAL EXPRESS

Re: Patent application entitled "Method and Apparatus for Application Driven Adaptive Duplexing of Digital Subscriber Loops"
Your Ref. No.: 01-OT-080
Our Ref. No.: 28940-116

Dear Xianbin:

Enclosed is a final draft of a patent application covering the above-identified invention along with a set of formal papers. The application has been amended in accordance with your recent comments and is now ready for execution. Please make another review of the application, and then execute the enclosed formal papers. All documents should then be returned to me for filing in the Patent and Trademark Office.

Very truly yours,

Andre M. Szuwalski

Enclosure

cc: Robert McCutcheon (w/o encl)

Exhibit C